Towards Accessibility Guidelines for the Metaverse

A Synthesis of Recommendations for People Living With Dementia

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ABSTRACT

Given the growing interest of corporate stakeholders in Metaverse applications, there is a need to understand accessibility of these technologies for marginalized populations such as people living with dementia to ensure inclusive design of Metaverse applications. We assessed the accessibility of extended reality technology for people living with mild cognitive impairment and dementia to develop accessibility guidelines for these technologies. We used four strategies to synthesize evidence for barriers and facilitators of accessibility: (1) Findings from a non-systematic literature review, (2) guidelines from well-researched technology, (3) exploration of selected mixed reality technologies, and (4) observations from four sessions and video data of people living with dementia using mixed reality technologies. We utilized template analysis to develop codes and themes towards accessibility guidelines. Future work can validate our preliminary findings by applying them on video recordings or testing them in experiments.

CCS CONCEPTS

• **Human-centered computing → Accessibility**; Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Mixed / augmented reality; Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Virtual reality; Human-centered computing → Human computer interaction (HCI) → Interaction devices; Human-centered computing → Human computer interaction (HCI) → Interaction techniques.

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KEYWORDS

Accessibility, Metaverse, extended reality, dementia, cognitive impairment, interaction, technology

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1 Introduction

As extended reality (XR) technologies have been explored for their use in various applications ranging from entertainment, gaming, training to healthcare, recent efforts have been focused on developing an immersive interconnected 3D virtual space known as Metaverse using XR headsets [9, 29, 32]. Different stakeholders drive the development of the Metaverse [35] and there are concerns of a lack of comprehensive accessibility guidelines for the technologies involved (e.g., for gaming in VR [14]). For instance, for the population of people living with mild cognitive impairment or dementia (PCI), XR has been mainly utilized to test the effectiveness of interventions (see [20] for a meta-analysis) with accessibility being rarely discussed. To our knowledge, the last systematic review of VR technologies for PCI has been conducted in 2020, but did not include augmented reality (AR) technology [12]. Furthermore, standardized guidelines helping in the accessible design of XR applications are still missing. There exist however guidelines for screening of touchscreen applications [18] and for the design of motion-based technology (MBT) [3] which typically features a non-immersive virtual space.

Since Metaverse applications use XR headsets, this study aims to develop accessibility guidelines for the design of XR technology and applications for PCI. On the lines of Astell et al.'s system development guidelines for MBT [3], we synthesized evidence for barriers and facilitators of accessibility for PCI in the broader context of XR.

2 Method

We employed a template analysis on literature, tests, video recordings, and session notes to determine barriers and facilitators of accessibility for PCI when interacting with XR technology. Our aim was to provide guidance for future XR technology and applications. Template analysis is a thematic analysis in which codes and initial themes can be created with subsets of data, allowing refinement and extension with each iteration in which new data is analyzed [21].

We collected and identified codes for the codebook from four main sources - (1) literature of XR use in PCI, (2) guidelines from touchscreen interaction, (3) reflections based on a familiarization with specific XR technologies, and (4) observations of PCI's interactions with XR technologies. To consolidate and structure the findings and to derive themes, codes and observations were added iteratively as sticky notes on a Miro board. We brainstormed the codes and categorized them using affinity diagramming. The codes resulted in a final codebook which will be used to carry out thematic analysis on the observation data.

The first author coded the literature on XR use in PCI using annotation tools within the literature management software Citavi. We define XR technology irrespective of the device employed, e.g., head-mounted displays (HMD), but also desktop monitors, including virtual reality and any technology between physical and virtual where both are combined by augmentation. The literature selection was carried out using a Google Scholar search combining the terms "augmented reality", "virtual reality", "mixed reality", "metaverse", "cognitive impairment", "dementia", "accessibility". Further literature was identified by analyzing the cited references from the studies included. Studies were screened and excluded if they did not provide findings regarding usability (e.g., only evaluation of the effectiveness of a treatment or lack of sufficient detail of the technology and application used) or did not include PCI as co-creators or participants. Reviews were considered if the summarized studies had not already been included in the coding process.

Second, we analyzed existing guidelines from the context of touchscreen applications [17, 18], hypothesizing that cognitive and sensory impairments lead to similar accessibility requirements in the context of XR. We utilized the coding procedure to abstract the specific findings in the source context before reflecting on their impact on the target context. For instance, the barrier of *interactive on-screen elements which could be accidentally touched* was coded as *robustness of interaction elements against unintended use* and then applied to XR interactions, e.g., *controller buttons which could be accidentally pressed.*

Third, we familiarized ourselves with the mixed reality technologies used in a dataset of video-recorded sessions of 22 participants living with dementia playing games on Hololens (Young Conker), Xbox Kinect (Kinect Sports Rivals Bowling), iPhone X (Stack-AR) and Osmo (Tangram; for a detailed description of the dataset, see [5–8]) to reflect on barriers in the setup procedure and while interacting with the technologies. While this familiarization does not replace an in-depth assessment with PCI, barriers experienced may already hint at issues also relevant for PCI. The objective of the familiarization phase was to develop an understanding of all the technologies before observing PCI's interactions with the technologies, facilitating interpretation of observations and feedback received from them. We took notes on how the technologies are setup and the interaction modalities they support, barriers we experienced and discussed how PCI would experience the same technologies. We found that the technologies were difficult to setup and would be very complex for PCI to get them started. That led us to focus our analysis also on barriers and facilitators to learn new technologies.

Finally, we analyzed observation data with 22 PCI playing games on Hololens (Young Conker), Xbox Kinect (Kinect Sports Rivals Bowling), iPhone X (Stack-AR) and Osmo (Tangram). The first author also attended four sessions in which PCI interacted with several motion-based exergames on Xbox Kinect (Kinect Sports Rivals Bowling, Climbing, Target Shooting; Tennis) and Nintendo Switch (Instant Sports Baseball, Bowling, Hurdle Race, Tennis, Just Dance 2022). Both observations of interactions as well as feedback provided by the participants were analyzed and codes were assigned. The technologies reviewed in addition to the reviewed literature are listed in appendix Table 2. The analysis of technologies for accessibility from the four sources described above was not sequential and often done simultaneously.

3 Results

The resulting code book comprises eight themes in three categories representing the processes for which accessibility measures should be taken, that is (1) perception, (2) comprehension, and (3) interaction. The ninth theme relates to all of these processes. An overview of the themes is shown in Table 1.

Table 1: Categorized themes with design considerations

Category	Theme
Perception	Perceptual guidance
	Ergonomic and aesthetic design
	Safety and health
Comprehension	Foster comprehension of goals, task, and motor steps
	Provide feedback
Interaction	Exploit bodily, motor knowledge
	Interaction simplicity
	Stabilize tracking
Perception, comprehension, and interaction	Accommodate individual capabilities

3.1 Perception

Perception of the XR technology and of the resulting blended space precedes and accompanies each interaction. For PCI, not only cognitive but also age-related physical (i.e., sensory) impairments can affect information retrieval. Furthermore, appearance and comfort play a crucial role in adopting and successfully using the technology.

3.1.1 Perceptual guidance

Existing guidance in the context of touchscreen applications includes reducing visual overload [17] and improving the visibility of task relevant interface elements [18]. Comparable findings are reported for VR applications [23, 24]. By making relevant interface elements salient and reducing distractive, non-informative elements, a negative influence of bottom-up guidance in perceptual processes can be prevented and the task-driven top-down guidance be supported (see also [33] for a model of visual attention in persons without impairments). We hypothesize that these findings can also be applied to the auditory modality, using salient and distinguishable sounds for feedback, and reducing noise that is prone to interfere with relevant output. Furthermore, to detect relevant information presented in either the physical or virtual space easily, required transitions in the blended space can be guided verbally [7].

3.1.2 Ergonomic and aesthetic design

Depending on the display and tracking technology, the use of mixed reality systems involves wearing hardware on head (HMD) and body (body trackers). An ergonomic design includes reducing the negatively perceived weight [1, 2, 15, 19, 28] and thus eliminating a potentially annoying distractor [4]. Furthermore, HMDs should be readily compatible with sensory aids (e.g., glasses and hearing aids) [1, 2, 31] which are regularly used due to age-related sensory impairments. Designing aesthetic hardware appears promising for reducing reported anxiety [23] as well as concerns of looking awkward and thus being stigmatized [15] while using the technology.

3.1.3 Safety and health

Regarding safety, attention needs to be paid to the implications of the limited or even non-existing field of view for the physical environment. This sensory limitation is relevant both in a physical and a cognitive way: First, not seeing and being aware of the entirety of the physical environment constitutes a safety concern for PCI, being possibly prone to falls. To reduce the risk of injuries, obstacles in the physical space need to be removed. Furthermore, the interaction space may be limited to an area considered as safe [28].

Second, several studies report anxiety, complaints and confusion of participants when they are no longer able to see their physical environment [19, 23, 24]. Besides taking organizational measures such as introducing a familiarization phase for a smoother transition between physical and real environment [23, 28, 31], technological approaches could contribute to relieve tension in people living with dementia. For instance, optical see-through displays could provide a more comfortable experience by dynamically modifying the glasses' transparency and thus allowing for a soft, fading transition into virtuality. Yamada et al. demonstrated that such displays could also be designed for VR applications [34]. In addition, the initial layout of the VR could adapt the real space and include avatars for other people in the room to provide a trustable environment and limit the rate of changes when entering virtual reality.

3.2 Comprehension

In order to engage in meaningful interactions with XR technologies, perceived information needs to be comprehended and interpreted in the context of the goals and tasks at hand. Once again, for PCI, guidance is required to cope with impairments in attention [25], executive functions and working memory [26].

3.2.1 Foster comprehension of goals, tasks, and motor steps

The cognitive demand required to interact successfully with XR technologies can be reduced by providing additional guidance regarding goals, tasks, and motor steps. First, the goals and respective tasks need to be laid out clearly [3]. Second, to enhance learning, instructions for task completion can be split up in motor goals and presented step-by-step [10]. Third, instructions need to be succinct and unambiguous [3].

3.2.2 Provide feedback

To compensate for impaired abilities of working memory in PCI [26, 30], feedback is crucial. Analog to findings for touchscreen applications [17, 18], providing feedback in the form of prompts and hints is also vital for XR technology [28]. Recommended feedback includes keeping PCI aware of the state of the interactive system [7] and of the success of interactions [23], guiding future interaction possibilities [24] and reminding PCI of resuming the fulfillment of begun tasks.

While prompts should be noticeable for the users, they should be designed not to place additional cognitive demand by interrupting an interaction. This can be achieved using sensible timing, i.e., differentiating between providing feedback on interaction success (immediately) and showing reminders (delayed) [3]. To ensure that prompts and feedback are noticed and sensory impairments do not break the perception-action loop, feedback can be coded in several sensory modalities [3, 8, 23]. If the information passed is compliant [31] or even redundant between the modalities, feedback can still be interpreted if information on a single modality has gone unnoticed. Furthermore, providing rich and realistic feedback may not only help PCI notice what is currently happening, but also facilitate using the obtained information to project possible future states of the XR system [8].

3.3 Interaction

To develop agency and to control state transitions within the XR system, PCI need to be empowered in performing actual interactions as system inputs. These interactions typically involve memorizing single steps and translating them into motor actions. Consequently, the design of interactions needs to comply with impairments in memory and motor coordination [16] occurring in PCI. Furthermore, disruptions of interactions due to tracking limitations should be avoided.

3.3.1 Exploit bodily, motor knowledge

Opposed to artificially designed interactions which require a learning phase and successful recall when performing tasks, natural interactions utilize existing experience and knowledge. Motor knowledge in particular has been proposed [22] and used for rotation [31] and gestural interaction [10, 19, 23, 24, 28]. Especially in fully immersive VR settings involving HMDs, representations of the users' hands can be added [19, 23, 24, 28] to counter motor coordination deficits in PCI [16].

Furthermore, affordances are proposed to ease functional interaction [15]. In non-immersive settings, physical affordances have shown to support the execution of known motor procedures [4, 6, 7]. Likewise, we observed that physical artifacts helped in executing appropriate interaction gestures (e.g., a ball which is physically grabbed in a virtual bowling game).

3.3.2 Interaction simplicity

To facilitate successful interactions and reduce failures, interaction procedures should be kept simple, allowing to recall the interaction steps, and fail-safe, preventing unintended input in the interactive system [10]. System development guidelines based on a previous review for MBT suggest limiting the spatial and motor complexity of interactions and making the interactive system more tolerant for minor deviances in their execution to accommodate the reduced motor and cognitive capabilities of PCI [3]. Supporting this notion, several studies using VR applications report difficulties of the participants due to their limited mobility [19, 28] and errors in repetitive movements leading to unintended interaction [24]. Likewise, additional complexity such as combining motor interaction with controller-based interactions should be avoided [23, 24].

3.3.3 Stabilize tracking

To preserve a consistent state of the blended or virtual space, it is vital that no interruptions in tracking occur. This requirement is easily violated if tracking systems with limited tracking space are used. That is, when body tracking fails, the representation of the limbs responsible for an interaction may freeze or become invisible, impeding successful interactions. For instance, we observed a participant in a wheelchair trying to compensate the inaccurate tracking quality in his seated position by shortly raising his hand to see it in the virtual environment before starting the actual interaction. While his compensation strategy was successful, we argue that interruptions or complete failure in tracking (e.g., tracking issues for wheelchair users [27]) can lead to confusion and frustration and subsequently prevent the adoption of technology for PCI. Similarly, when objects to be tracked are temporarily occluded, the XR application may fail to communicate the system state appropriately to its user.

Consequently, we argue that limitations in tracking need to be addressed. That is, the tracking technology used should ensure coverage of all relevant objects, for instance, by using more than one tracking unit, or attaching motion sensors to the user's limbs. Additionally, the receiving application needs to be designed to be more error tolerant. That is, it needs to remain in a consistent state and recognize tracking errors as well as provide guidance to resolve them. In settings where people with different assistive devices co-use the technology, the tracking range should be easily adjustable to these people's body height and posture.

3.4 Accommodate individual capabilities

As outlined by Astell et al., individual abilities of people living with dementia vary considerably, thus rendering customization possibilities a requirement of inclusive and frustration free technology [3]. This requirement applies for sensory (e.g., visual and auditive) and cognitive [28] as well as physical capabilities [23, 31]. Additionally, the impact of assistive devices on the ability to interact needs to be considered carefully. For instance, the mobility constraints of wheelchair users may require designing alternative ways of navigation (see e.g., Gerling et al.'s study assessing VR design implications for wheelchair users [13]).

4 Discussion

While different parties work in an growing effort on establishing applications for the Metaverse [35], there is still a lack of comprehensive accessibility guidelines for people living with impairments such as PCI for that context. To ensure that no barriers for PCI are introduced when designing for the Metaverse, their abilities and impairments need to be noticed and considered.

In this work, we present themes guiding the development of accessible XR technologies for PCI based on findings of studies employing AR and VR for people living with dementia, on findings derived from other interactive technology, as well as on observations and tests. Consistent with insights for MBT, our findings tackle physical as well as cognitive constraints [3]. The categorization of our findings highlights the role of requirements in the process of perceiving, comprehending, and interacting for a successful use of technology. These findings are not meant to be exhaustive but should provide a starting point for considering and testing manipulations in the design of technology and applications for the Metaverse. Thus, we expect that our guidance can be complemented by further aspects relevant for the Metaverse, e.g., social aspects [12] including virtual communication, technical constraints coming with distributed systems, and the efforts to setup VR technology [11].

To develop guidance that practically empowers PCI to use XR technology, we integrated both the direct impact of requirements stemming from dementia (e.g., regarding memory and motor coordination) as well as the reported impact of requirements stemming from frequently co-occurring age-related impairments (e.g., regarding sensory or mobility impairments) in our analysis. While we hope that this approach covers the lived reality of PCI well, an alternative structure of our findings could make the impact of different impairments on the derived guidance more graspable.

Even though we included more recent findings and studies involving augmented reality in our analysis compared to Flynn et al.'s review, we see several parallels in their recommendations and our findings (e.g., regarding feedback). Furthermore, we acknowledge that tensions may exist between the reported themes when applying them in the design process. For instance, aiming for an intuitive (i.e., cognitively accessible) interaction mode (theme *exploit bodily, motor knowledge*) involving natural gestures can only be realized to the degree that mobility and motor impairments do not restrict required movements (theme *accommodate individual capabilities*). While these tensions mean more effort in the design process, we argue that they at the same time encourage designers to apply a more holistic understanding of accessibility rather than limiting considerations on a narrow definition of an impairment.

As future work, the developed themes and codes should be validated using further observations of PCI interacting with XR technology. By that, we hope to refine our findings as well as to interpret the relevance of the design recommendations by relating them to the participants’ behaviors.

5 Conclusion

With the growing engagement in establishing applications for the Metaverse, there is an urgent need for accessibility guidelines to help designers create an environment open for all people. We collected and synthesized recommendations for making XR technologies usable for PCI as a first step towards accessibility guidelines.

As a next step, our findings can be applied on a dataset to make them more robust. The design recommendations obtained can inform practitioners in the development of XR technologies and applications for the Metaverse.

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A APPENDICES

Table 2: Technologies reviewed in familiarization and observation data

Technology	Applications
Microsoft Hololens	Young Conker
iPhone X	Stack-AR
Osmo	Tangram
Microsoft Xbox Kinect	Kinect Sports Rivals Bowling, Climbing, Target Shooting, Tennis
Nintendo Switch	Instant Sports Baseball, Bowling, Hurdle Race, Tennis; Just Dance 2022